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Review

Coffee cultivation techniques, impact of climate change on coffee production, role of nanoparticles and molecular markers in coffee crop improvement, and challenges

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Abstract Coffee is the most frequently consumed functional beverage world wide. The average daily coffee consumption is increasing. This crop, which plays an important role in the global economy is under great threat from climate change. To with stand the current climate change, farmers have to learn crop cultivation techniques, strategies to protect crops from diseases, and understand which type of seed varieties to use to avoid crop loss. The present review briefly discusses the coffee cultivation techniques, impact of climate changes on coffee production, processing techniques of coffee, and the importance of coffee in our society, including its chemical composition and prevention against, major diseases. Furthermore, the importance and role of advanced nanotechnology along with molecular approaches for coffee crop improvement and facing challenges are explained.

Keywords Agriculture, climate change, coffee, CRISPR/Cas9, molecular marker, nanoparticle (NP)

Introduction

Coffee (*Coffea arabica* L.) belongs to the Rubiaceae family and it is the world-famous beverage with the second-most traded commodity after oil. Baba Budan first planted the coffee plant in Mullayanagiri hills Chikmagalur district of Karnataka state (Anamika 2018). Tea has the first place and coffee is the second most important beverages crop of India. It is indigenous to abyssinia plateau (Ethiopia) from where it was taken to Arabia in the 11th century. Coffee is a brewed drink prepared from coffee beans, which will give instant energy and relaxation. This coffee genus contains 100 species of tropical trees and shrubs. This genus was first discovered in the 18th century by the Swedish botanist Carolus Linnaeus. Coffee species originated from Ethiopia (Davis et al. 2012). 7 countries are cultivating large-scale coffee; those are Brazil, Vietnam, Colombia, Indonesia, Ethiopia, India, and Hondurans. This is the world's most important agricultural commodity. It represents a major source of revenue for more than 40 tropical countries, generating more than 120 million jobs. In the present review, we discussed the effect of climate change on coffee, the importance of coffee in human health & society, suitable conditions for the coffee cultivation, and seeds preparation for sowing and nursery practices. Moreover, plantation and irrigation techniques, harvesting and roasting process, major diseases and chemical compounds in coffee plants and explained impact of nanotechnology and molecular markers for coffee crop development as well as the challenges.

Coffee Plant Growth Cycle

Coffee species are small trees and native to tropical and southern African and tropical Asia. Generally, 1 ~ 2 months will take for seed germination and 3 ~ 4 years will take to get the plant mature for flowering. The life span of the coffee pants is 80 years with 12 feet in height. Flowers are in white with a good smell. Self-pollination in *arabica* and cross pollination in *robusta* can take place (Adhikari

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et al. 2020). After less than two weeks, the flower will develop into coffee cherries. Initially, the berries are in green color and turn into deep red color. Finally, the harvesting can do at the deep red stage.

Impact of Climate Change on Coffee Cultivation

India contains so many languages. As per Koppen classification, India comprises a wide range of weather conditions. December-February (winter), March-May (summer), June-September (Rainy season (Monsoon), and October-November (Post monsoon). The average temperature in India is 25~37°C. Altitude is the most important factor for the coffee cultivation process. *Arabica* needs 15~28°C and *Robusta* needs 20~30°C of optimum temperatures, 70~80% of rainfall (De Camargo et al. 2010; Wintgens et al. 2012) and other conditions to survive healthily those details were mentioned in Table 1. Higher temperature reduces photosynthesis and chlorosis can occur (Bunn et al. 2015; Da Matta et al. 2006). Climate is a key factor for successful coffee production. Drought, salt, high temperature, storms, and strong winds decrease flower production and increase the risk of small beans production. These climate changes show a direct impact on coffee quality and productivity levels (Jarrod et al. 2021; Legesse 2019). Similarly drought and salt stress limit the coffee production. Drought causes the water deficit in plants and reduces the cell turgor to fall down at its maximum value and during drought stress, plant physiological structure get disturb, so that coffee production will be decrease (DaMatta et al. 2006). Sufficient water availability is a very crucial aspect for coffee plants to give a high yield. As a result of heavy rains and excess moisture, many plantations have been face the black rot incidents, bean droppings, face a threat for ripe cherries, cherries become blackish color and some cherries will get cracking. This type of bean gives less good taste (Jarrod et al. 2021; Poltronieri and Rossi 2016) and cost will be very less in market.

Coffee diseases

Coffee production is decreasing gradually by the effect of fungal, bacteria, nematodes, and parasitic diseases (Banavath et al. 2019; Roberts, 2013). Coffee berry borer (*Hypothenemus hampei*) disease is a major threat which laying eggs inside the fruit so that more damage will occur to

Table 1 Some favorable conditions of Arabica and Robusta coffee plants

Factor	Arabica	Robusta
Soil	Sandy loam soil (pH5-6)	Same as Arabica
Slope	Gentle-to-moderate slopes	Gentle slopes to fairly level fields
Elevation	1000-1800m	500-1000 m
Temperature	15-28°C; cool, equable	20-30°C
Relative humidity	70-80%	70-80%
Annual rainfall	150-250 cm	100-200 cm
Blossom showers	March-April (25-40 mm)	February–March (25-40 mm)
Backing showers	April-May (50-75 mm), well-distributed	March-April (50-75 mm), well-distributed
Fruiting	120-150 and 180-210 days after blossom	160-195 days after blossom
Disease	Moderately disease tolerant	Less disease tolerant
Falling of flowers	15-20%	20%
Yield	800-1000 kg/ha	500-900 kg/ha

Table 2 The common nutrients and fertilizers of coffee plants

Plantage (Year)	Nutrients (kg/ha)			Fertilizers (kg/ha)		
	Nitrogen	P_2O_5	K_2O	Ammonium nitrate	MAP	Multi-K
1	30-40	0	30-40	60-65	0	65-90
2	60-80	0	60-80	130-170	0	130-175
3	120-160	20-30	150-200	220-280	30-50	330-450
Maturity	200-300	30-50	250-400	360-520	50-80	550-870

Table 3 Some important diseases, symptoms, causative agents, and their prevention methods incoffee plants

Type of organism	Causative agent	Disease name	Symptoms	Prevention method
Bacteria	*Pseudomonas syringae*	Bacterial blight	Leaves become brown and necrotic with yellow halos; finally, leaves turn black and die. Symptoms occur on secondary or tertiary branches.	De-sucker or cut off infected twigs and collect them in buckets for burning. Treat with copper oxychloride, Agrimicine, or Distreptine 20.
Bacteria	*Pseudomonas syringae* pv. *tabaci*	Bacterial leaf spot (BLS)	Small brown lesions on leaves, becoming black and angular.	Apply copper to the plants just before the onset of the rainy season.
Bacteria	*Pseudomonas cichorii*	Bacterial leaf blight (BLB)	Leaves associated with lesions.	Spray copper oxychloride or Agrimicine.
Bacteria	*Xylella fastidiosa* subsp. *pauca*	Coffee leaf scorch (CLS)	Leaf chlorosis and defoliation; finally, leaves fall down.	Apply copper containing fungicides.
Fungal	*Cercospora coffeicola*	Cercospora leaf spot (brown eye spot, berry blotch)	Brown spots on foliage enlarge and develop a gray-white center and a red-brown margin.	Spray copper-related fungicides.
Fungal	*Colletotrichum kahawae*	Coffee berry disease (CBD)	Dark sunken lesions on green berries; finally, berries drop from the plant.	Treat with fungicides (e.g., chlorothalonil, fluazinam, dithianon, azoxystrobin).
Fungal	*Hemileia vastatrix*	Coffee leaf rust (CLR)	Pale yellow spots appear on leaf surfaces and powdery orange-yellow lesions on the bottom of the leaves.	Spray copper-containing fungicides.
Fungal	*Fusarium stilboides* Wollenw.	Seedling blight	Cotyledons often fail to unfold, stem has necrotic lesions, and seedlings wilt.	Remove the diseased seedlings from the field and burn.
Fungal	*Fusarium xylarioides* and *Gibberella xylarioides*	Coffee wilt disease (CWD)	Leaves turn yellow, dry wither, and fall. Finally, within a few weeks, the entire tree withers and dies.	Chemical treatments do not protect the trees against this disease. Apply antiseptic paste on the injured parts to avoid the penetration of pathogens.
Fungal	*Colletotrichum* sp.	Blister spot	Leaves with emaravirus lesions	Treat with a systemic fungicide (e.g., Benlate).
Fungal	*Capnodium coffeae* Pat.	Sooty blotch mold or sooty fungus	Whitish mealy bugs and black papery films of fungal growth on leaves and berries.	
Fungal	*Corticium koleroga*	Coffee thread blight (CTB)	Mats and light-colored thread growths on the bottom of the leaves and twigs.	Spray cupric compounds, triazole fungicides (e.g., Agrozim 50 WP, Bavistin 50 WP, Bayleton 25 EC, Foltaf 80 WP, Plantvax 20 EC, Tilt 25 EC, and Topsin-M 70 WP).
Fungal	*Pellicularia koleroga*	Koleroga	Fine whitish threads on the branches and twigs finally, leaves wither and dry	Spray Bordeaux mixture and Bavistin 50 WP.
Fungal	*Marasmius equicrinis*	Horse hair blight	Leaves and twigs covered with long thin black threads. The diseased leaves wither and die.	Spray cupric compounds or fungicides. Carefully remove the infected branches and part sand burn.
Fungal	*Corticium salmonicolor*	Pink disease	Salmon-pink crusty coating on the surface of the bark, which pales later on. The diseased parts wither and die.	Spray cupric fungicide. Remove diseased branches and burn.
Fungal	*Phoma costarricensis*	Burn or blight	Leaves show necrosed tissues with the development of sickle shape.	Treat with cupric fungicides and organic fungicides (e.g., Rovral).
Fungal	*Colletotrichum gloeosporioides*	Anthracnose	Leaf yellowing, leaves drop at mid-branch. Spots or lesions on ripening berries.	Maintain healthy coffee plants. Clean the area. Remove waste branches from the field and burn.
Fungal	*Armillaria mellea*	Armillaria root rot	Yellowing and wilting of the foliage, followed by death.	Remove any dead stumps and their roots. Cleanthe area. Remove waste branches from the field and burn.

Table 3 Some important diseases, symptoms, causative agents, and their prevention methods incoffee plants (continued)

Type of organism	Causative agent	Disease name	Symptoms	Prevention method
Fungal	*Fusarium stilboides*	Bark disease	Fungus grows beneath the bark layer that becomes flaxy in texture. Damage to stem and berries.	Spray with 0.4%fungicide (Captan or Captafol)
Fungal	*Rosellinia spp.*	Black or Rosellinia root rot	Fungal growth on the root surface reduces the root system and causes wood rot. Finally, root cortex with lesions	Spray with fungicides.
Fungal	*Colletotrichum gloeosp-orioides,* and *Colletotrichum kahawae*	Brown blight	Brown sunken lesions on fully-developed cherries, which turn black and hard (can be confused with Cercospora)	Maintain healthy coffee plants. Remove waste branches from the field and burn.
Fungal	*Koleroga noxia*	Black rot disease	Dark brown or black decaying leaves, mycelial threads on twigs and petioles	Avoid close planting. Removeand burn dried and dead branches. Spray 1% Bordeaux mixture and Carbendazim 50 WP on the surface of leaves and berries.
Fungal	*Colletotrichum gloeosporioides*	Stalk rot of berries and leaves	Brownblack necrotic lesions on the nodes and internodes, greenwood branches toward the apex	Spray Bordeaux mixture and Carbendazim 50WP to foliage, branches, and developing berries.
Fungal	*Hemileia coffeicola*	Grey leaf rust	Clear spots and unevenly spread blotches on the leaf surface	Spray cuprous oxide (Red Copper) with 50% copper content.
Fungal	*Omphalia flavida*	American leaf spot	Round spots on leaf limbs	Spray lead arsenate and copper-based fungicide (e.g., Bordeaux mixture).
Fungal	*Sclerotium rolfsii*	Soft rot disease	Water-soaked lesions on leaves and berries, leading to softening and decaying of infected tissues	Spray Bordeaux mixture and Carbendazim 75 WP on both surfaces of leaves and berries.
Fungal	*Cercospora coffeicola*	Berry blotch	Dark brown, irregular, slightly sunken, necrotic spots on the surface of green berries	Spray 1% Bordeaux mixture.
Fungal	*Cercospora coffeicola*	Red blister disease	Small red spots on both green and ripening berries	Spray fungicide.
Nematode	*Pratylenchus* spp.	Root knot	Stunning leaf becomes yellow.	Crop rotation is the best treatment.
Animalia	*Xylosandrus compactus*	Shoot hole borer	Small holes on the undersurface of young succulent branches between nodes, finally, branches wither	Remove and destroy all the unwanted and infested suckers during summer. Simultaneously, spray systemic fungicide (e.g., Propiconazole and Endosulfan 35 EC).
Animalia	*Xylotrechus quadripes*	White stem borer	Presence Ridges on the stem, yellowing of leaves. Grubs bore into the branches and cause wilting and occasional drying of plants.	Prune infected plants or uproot them. If the borer has burrowed up to the root, then burn the infected plants and spray Chlorpyrifos 20EC. Stem may be swabbed with Carbaryl 50WP.
Animalia	*Xylosandrus compactus*	Black twig borer	Yellowing of foliage and wilting, often at end of twigs and branches	Destroy the infected plant areas and burn.
Animalia	*Hypothenemus hampei*	Coffee berry borer (CBB)	When the insect feeding starts from the small hole of the fruit, debris will come out, and brown or grey debris deposits on top of the hole and drop the fruit.	Remove dropped berries and debris fromthe field to reduce the new source of infection. Spray insecticides.
Algae	*Cephaleuros virescens*	Algal (red) leaf spot	Furry growth and green-orange spots on leaves and cracks in the barks of the young stem	Spray cupric fungicides and organic fungicides.

Table 4 Some medicinal benefits of chemical components in coffee

Component name	Part	References
Caffeine ($C_8H_{10}N_4O_2$; 1,3,7-trimethylxanthine)	Beans	Abdulmumin 2014
Chlorogenicacid (5-caffeoylquinicacid; 5-CQA)	Green beans	
Diterpenes ($C_{20}H_{32}$)		
Trigonelline (N-methyl nicotinic acid)		
Phenylalanineammonia-lyase (PAL)	Young leaflets	Thomas 2006
Phenylpropane ($C_9H_{12}S$)		
Methylxanthine (3,7-dihydropurine-2,6-dione)		
Theophylline ($C_7H_8N_4O_2$)	Petals and stamens	
7-Methylxanthosine		Ramalakshmi and Raghavan 1999
7-Methylxanthine		
3,7-Dimethylxanthine		
Melanoidins	Beans	Passos et al. 2021.
Alkaloids		Diviš et al. 2019; Iriondo-DeHond et al. 2021; Katarzyna et al. 2021
Cafestol ($C_{20}H_{28}O_3$) and kahweol ($C_{20}H_{26}O_3$)	Coffee beans	
Caffeoylquinic acid ($C_{16}H_{18}O_9$)		
Glucuronic acid ($C_6H_{10}O_7$)	Green coffee, roasted coffee beans	
Triglyceride ($C_6H_8O_6$)		
Stigmasterol and sitosterol		
Linoleic, linolenic, oleic, palmitic, stearic, arachidic, lignoceric, behenic acid		
Fatty acids with pentacyclic		
Waxes		
Tocopherols ($C_{29}H_{50}O_2$)		
Phosphatides		
Nicotinic acid (pyridine-3-carboxylic acid)		
Aliphatic acids and quinic acid	Coffee beverages or drew	
N-Methylpyridinium Serotonin		
Spermine and spermidine		
Carbolins (norharman and harman)		
Vitamins (B1, B2, B3, B6, B9, C, E, K)		
Acrylamide		
Furan		
N-alkanoyl-5-hydroxytryptamides		
g-Aminobutyric acid (GABA)		
Sucrose ($C_{12}H_{22}O_{11}$)	Petals and stamens	Ramalakshmi and Raghavan 1999
Pectin ($C_6H_{10}O_7$)		
Starch $(C_6H_{10}O_5)_n$		
Pentosan ($C_{10}H_{18}O_{21}S_4$)		
Hemicellulose ($C_5H_{10}O_5$)		
Holocellulose (fiber) $(C_6H_{10}O5)_n$		
Lignin		
Oils		
Protein		
Ash		

Table 4 Some medicinal benefits of chemical components in coffee (continued)

Component name	Part	References
Sugars (mannose, galactose, arabinose)	Beans	Passos et al. 2021
Caffeic acid	Roasted beans	
Polysaccharides (cellulose, arabinogalactan, galactomannan)	Green coffee, roasted coffee beans	Diviš et al. 2019; Iriondo-DeHond et al. 2021; Katarzyna et al. 2021
Oligosaccharides (stachyose, raffinose)		
Monosaccharides (glucose, galactose, arabinose, fructose, mannose, mannitol, xylose, ribose)		
Feruloylquinic acids (3-, 4-, and 5-FQA)	Young leaves	
Isomers of monoesters (3-, 4-, and 5-CQA) and diesters (3,4-, 3,5-, and 4,5-diCQA)		
Hydroxycinnamoylquinic acids		
Variousiridoid glycosides, tannins, andanthraquinones		
Mangiferin and isomangiferin		
3,4-Dicaffeoylquinic acid		
Caffeine xanthinemethyltransferase 1, methylxanthinemethyltransferase 2, and dimethylxanthinemethyltransferase		
Theobromine1-N-methyltransferase		
Uric acid, allantoin,allantoicacid, and urea		
Furanones, acetaldehyde, propanal, and methylpropanal		
Adenosine nucleosidase		
Polyphenol oxidases	Early development leaf	

crop. When the larvae hatch, they consume what is left in the berry, eventually turn it to rotten bacterial diseases include halo blight, leaf spot, and coffee leaf scorch and these diseases responsible for significant reductions in coffee yields (Muller et al. 2009). Fungal diseases damage the coffee plants enormously (Holger et al. 2011). Some disease names, symptoms, prevention methods and, their causative agents of coffee are mentioned in Table 3

The role of coffee in human health and society

By taking coffee so many health benefits can occur that is body relaxation and give extra energy by avoiding stress. Many medicinally important compounds present in coffee include chlorogenic acid, feruloyl quinic acids, various iridoid glycosides, isomers of monoester, diester caffeoylquinic acids, and dioxoanthracene (Banavath et al. 2019; Mondolot et al. 2006). Those chemical components are listed in Table 4 and it protects our body cells from damage by developing antioxidants and it helps to prevent cardiovascular disease, cancers of the kidney, liver, and premenopausal breast.

It plays a crucial role in gastrointestinal, dermatological, cardiovascular, and nervous system (Jae-Hoonbae et al. 2014; Patay et al. 2016). It also decreases memory loss, type-2 diabetes and protect from Alzheimer's and Parkinson's disease (Juliana et al. 2019; Monteiro et al. 2012; Pourshahidi et al. 2016). Some important benefits are there to socialize with coffee those are many people's start the coffee shops for public interest hence, employment source can be generate. Coffee will give instant energy to public workers, who were involved in heavy works and a coffee shop makes a great place to chat about their problems and solutions with close friends and neighbors while drinking the coffee (https://www.coffeeandhealth.org/all-about-coffee/coffee-society/). Generally, it offers an environment which makes everyone feel happy and comfortable so that neighbors maintain good relationships with each other. It helps who tired with more work tension in the office, they will get extra energy and mind relax by drink cup of coffee so that work will become fast (https://www.streetdirectory.com/food_editorials/beverages/coffee/coffee_its_silent_role_in_our_society.html; https://www.kibin.com/essay-examples/the-significance-of-coffee-in-society-today-ZPBXb8P1).

Suitable conditions to grow the coffee plants

Coffee plants can grow at low lands, and at high lands, altitude ranges between 1400 and 1800 meters (Da matta & Ramalho, 2006; Davis et al. 2012; Dias et al. 2007;

Holger et al. 2010). It needs 150 to 250 cm rainfall with a temperature between 15 to 28°C and it needs both moderate sunlight and shade. It doesn't tolerate strong sunshine, snowfall, temperature above 32°C. At plants' growth stage needs shade however at flowering and fruit set stage needs sunlight (not direct sun) (Davis et al. 2012; De camargo 2010). At the fruit ripening stage, dry weather is most essential otherwise fruits get damage. The plants need nutritionally rich and sandy loam & soil moist which rapidly store the water and drain excess water from the soil. These plants grow vertically, perennial bush with green foliage and glossy appearance. Majorly grown on northern and eastern hills slopes at elevations from 600 to 1,600 meters above sea level for the less exposed to strong sunlight and south- west monsoon winds.

Preparation of seeds for sowing and nursery practices

Healthy and well-developed fully ripe berries were harvested from specially identified plants to use as seed. After harvest the fruits, soak in water so that less quality seed fruits get float on water. After discarding the floated fruits, the weight and good fruits are de-pulped, sieved then mixed with sieved wood ash and dry under shade (Krishnaraju 2008). Later allow for seeds grading to remove all cut, triangular, and damaged beans. Before Sow in small pockets, seeds are treated with Agrosan-B or organomercurial compound to prevent fungal infection and Azospirillum and phosphobacterium to avoid bacterial diseases to the root system (Krishnaraju 2008). Seeds are sown in December-January months. After sowing the seeds in pockets, those pockets has to cover with a paddy straw to avoid the evaporation of water and for shade. Watering daily is important to protect the plants from direct sunlight by an overhead pandal till 40cm height of plantlets. (http://www.agritech.tnau.ac.in/horticulture/horti_plantation%20crops_coffee.html). Later Plant lets are transferred to nursery (Generally coffee plants will develop by seeds or vegetative propagation). 3-4 years will take to develop plants from seeds to first flowering. Development of the coffee plants by seeds are taking more time than the vegetative production because seed germination takes more time although ratio of the seeds germination are less. Hence, most of the people follow vegetative propagation (Krishnaraju 2008; http://www.agritech.tnau.ac.in/horticulture/horti_plantation%20crops_coffee.html).

After risen the plantlets by seed or vegetative propagation, remaining steps were taken under nursery conditions. Plantlets were transferred in the polythene or a small handmade bag contains 30-40 kgs of well rotten compost along with 2 kgs of finely sieved agriculture lime, and 10 g of rock phosphate. Monthly twice, urea applies is necessary for the strong and healthy growth of the plants. 10% of the plants may die, because due to not proper acclimatization and sensitivity of the plants. The remaining 90% of the plants survive healthily. Eventually, plant price can decide based on the healthy and grade (height) of the plant (http://www.fao.org/3/ae939e/ae939e04.htm; Krishnaraju, 2008). The generally used nutrients and fertilizers for the coffee crop were shown in Table 2. *Robusta* required less fertilizer than *Arabica*. Foliar spraying with multi-K to soil is the most effective way to improve potassium and nitrogen uptake by the coffee plants. This method prevents the adsorption or leaching of potassium and nitrogen to the soil. Good yield and quality were improved by the foliar spraying with multi-K (https://www.haifa-group.com/foliar-nutrition-coffee-trees-benefits-spraying-multi-k)

Preparation of field for plantation

Sandy loam soil is suitable for coffee growth and the soil pH of 5-6 is preferable. The land has to prepare by giving 4 or 5 plowings and harrowing to bring the soil to fine tilth stage. After summer rain, dugs have to make by the distance of 1.25-2.5 meter (Reddy 2019; Krishnaraju 2008). The pits are left open for a week for weathering. Before planting, it is advisable to add the soil micro and macronutrients along with the phosphorous, lime, and 500 g of rock phosphate have to mix with soil in the pits. Generally silver oak, Dadaps, Ficus, Albizia, Led back, and Gliricidia maculate trees are used for shading purposes. These coffee plants cultivation not only under wild tree shade, but they can also grow under horticultural plants like big Mango, Jock fruit, and *Azadirachta indica* (Neem) (Krishnaraju 2008).

Irrigation of coffee plants and benefits with mulching technique

Irrigation depends on the type of soil and presence of moisture level in the soils. Generally, 4 types of irrigation methods are followed by farmers. Surface irrigation, drip irrigation, sprinkler irrigation, and Perimeter irrigation system. When farmers cultivate on the plane lands they will use drip irrigation and sprinkler irrigation. Cultivating under shade houses they will follow perimeter irrigation. Every 5 to 8 days interval watering is good because more wetness can result in fungal disease attacks to plant roots (https://www.agrifarming.in/coffee-growing-information-beginners). To avoid the weed Dalapon and Amino salt 2, 4-D sodium salt 20% weedicide can be used. Generally, mulching technique can be use to prevent the weed. This technique can make enrich the soil moisture and improves the soil texture.

Mulching provides many benefits to the farmers; it prevents water evaporation from the soil, easy to weed control, and develops a microclimate near the plant root zone. Mainly, the plants grow healthily and protect the root system from climate change. Moreover, it acts as a barrier to soil pathogens and helps to reduce soil erosion. Fertilizers which we use for crop development will not become waste by uptake the weeds eventually, crop will give a good yield. More over the crop field will be clean (Mwango et al. 2015; Nzeyimana et al. 2017; Nzeyimana et al. 2020; Thankamani et al. 2016; Wu et al. 2016).

Harvesting, Post harvesting, and Roasting process of the coffee beans

Farmers follow 4 steps of harvesting technique. Harvesting starts when the coffee cherries are bright red and glossy. Fly picking: This is small-scale picking, early ripe berries only can harvest in this step. Main picking: Fully ripened and completely formed berries can harvest in this step. Stripping: All the berries left on the plant irrespective of the ripe were harvest in this step. Cleaning: involves collecting the all fruits which have been dropped during harvesting (Mesfin et al. 2019; https://www.coffeemasters.com/coffee-101/harvesting-of-coffee/). After harvest, the ripened and unripe fruits have to be separate properly to get the good quality of the coffee beans. However, fruits have to wash three to four times properly than allow drying under moderate sunlight for two days later grading should be done based on size and shape with the help of a rotating sieve. Carefully remove the beans from the coffee fruits by machinery and allow for dry. After proper drying, allow the beans to pack and store in moisture less, clean, and well-ventilated storerooms. Eventually, these packed beans will transport to coffee roaster mills. Initially coffee beans will be green in color, beany and grassy aroma with not smell like coffee. The roasting process can be decides the coffee taste, odor, and aroma. Different roast profiles will give the different tastes of the coffee, small batch roasting of green beans will conduct at home for personal consumption. Even after the term of the 20th century, it was more common for at-home coffee drinkers to roast their coffee in their residence. Machine roasting is a very accurate method than the other methods because we can set the exact temperature for roasting and the rotation of beans takes place uniformly. Every few seconds once the beans have to check by experts for the perfect color and taste. When the desired result is achieved, roasting will stop and allow beans to become cool. Eventually, packing technology is designed to protect and preserve the essential flavors and aromas of the beans with vacuum package for safety purposes. Light roasting temperature 180°C-205°C (356°F-401°F), medium roasting temperature 210°C (410°F)-220°C (428°F), Medium dark roasting temperature somewhat spicy 225°C (437°F)-230°C (446 °F) and dark roasting temperature 240°C (464°F) 250°C (482°F) (https://en.wikipedia.org/wiki/Coffee_roasting).

Uses of coffee by-products

Coffee plants produce many by-products and their uses are mentioned below.

Flower

Coffee plants produce white, multi-flowered and cymosely inflorescences. Every plant produces 30,000-40,000 flowers per year and it contains about 1 g casein /100 g dry weight. Through the green process, the flower can use for the production of bioactive compounds, melanoidins, and bio-sugars (Nguyen et al. 2019) and Coffee blossom tea can prepare with dried flowers (Tizian et al. 2020).

Leaf

The leaf contains green in color, in some areas consumed it as leaf infusion as traditional food and it contains many secondary metabolites (Campa et al. 2018; Jyotshna et al. 2016; Patay et al. 2016; Ross 2005) and used as a coffee leaf tea (Tizian et al. 2020).

Cherry pulp

These cherry pulps are used for the preparation of jam, juice, and jelly. The pulp flour can be used for the preparation of pieces of bread and sauces (Naidu et al. 2004; Ramirez and Jaramillo 2011).

Cherry husks

Cherry husks can also be used for the cultivation of microorganisms based on their high fiber content and citric acid and gibberellic acid can be prepare by fermentation process (Tizian et al. 2020).

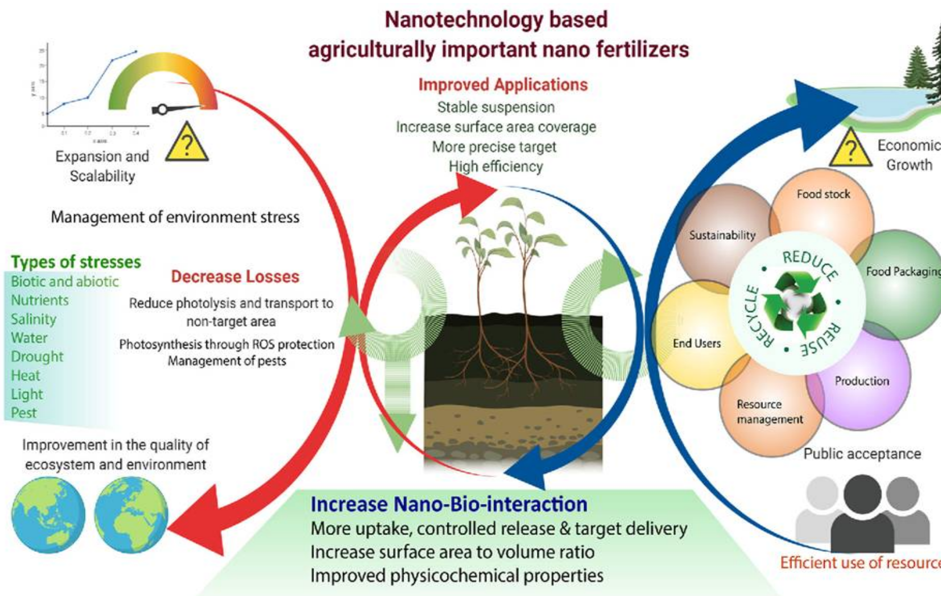

Fig. 1 Nanotechnology-based agriculturally important nano-fertilizers increase agronomic productivity, and efficiency and reduce environmental stress

Nanoparticles for coffee crop improvement

To provide suitable coffee products for the growing population in today's society, plants have to grow for which will overcome the biotic and abiotic stress. During these days, agricultural crops getting damage is mostly due to soil-born phytopathogens, insects, pests, and parasites. The using of fungicides and pesticides to protect the plants from disease is indirectly contaminating the soil and surrounding environment. Hence, to overcome these problems, fertilizers containing nanoparticles (NPs) made by nanotechnology can be used to protect the plants, soil, and environment. Wang et al. 2020 have been used NPs to cultivate coffee plants. The applying of NP-fertilizers to coffee plants create an environment conducive to plant growth near the plant root system and these NPs passed in through the root system to influence biological responses i.e. signal transduction and nutrient absorption were observed. Similarly, Mahendra et al. 2018 was used copper NPs contain fertilizers to protect against fungal diseases like blight, downy, powdery mildew, and rust in coffee plants. Same copper Nps were used on coffee, Soyabean, and eggplants to protect from fungal diseases (Sung-Hyun et al. 2021). Recently, coffee extracts had been used to synthesize very small silver NPs (Dawadi et al. 2021). Nanotechnolgy based agricultural importance were shown in Figure 1.

In 2013 Van et al. was grown some coffee plants under greenhouse conditions. After 8 weeks, he separated some plants and allowed them to grow some plants with normal water and some plants with chitosan NPs with concentrations of 10, 20, 30, and 50ppm. Eventually, he observed 10ppm concentrated plants exhibited good morphological and physiological parameters than the control plants. Similarly, these chitosan NPs were exhibited good growth, enhanced biochemical (Antioxidative enzyme levels) parameters and defense mechanisms in Vicia-feba seedlings & maize plants than the control plants (Abdel-Aziz 2019; Kumaraswamy et al. 2019). Later Lorenzo et al. (2019) applied Zn NPs and $ZnSO_4$ separetly to one-year-old coffee *arabica* plants under greenhouse conditions, later morphological & physiological assays were conducted. Zn NPs treated plants showed higher biomass and photosynthetic rates than the control plants. Based on the above discussion, NPs can be used to protect the plants from diseases and also enhance the physiological and biochemical parameters.

The NPs was used not only on coffee plants, it also used in vegetables and fruit crops (Sung-Hyun et al. 2021). Moreover, the prepared silver and gold NPs from green and roasted coffee beans were used in the pharmaceutical industry, diagnostic medicines, and inflammatory gel preparations to reduce the antioxidatives, obesity, inflammatory reaction, and on other health issues (Antonio et al. 2017; Baghaienezhad et al. 2020; Dhand et al. 2016; Nurman et al. 2019; Soesilowati et al. 2020; Sunoqrot et al. 2021; Wanderson et al. 2019).

Role of Molecular markers and CRISPR/Cas9 technology for crop improvement

Some coffee plants were (IAPAR59 and Rubi) grown under drought and normal conditions, after a few days the molecular changes in the shoot apices were studied. Interestingly, the *CaMAS1, CaSTK1, CaSAMT, CaSLP*, and *nsLTP* genes up regulations were observed in drought conditioned IAPAR59 plants (Luciana et al. 2016). Similarly, plants thrive in drought conditions, which mean they have drought-tolerant genes and candidate genes like *CaMYB1, CaERFO17, CaEDR2, CaNCED, CaAPX1,* and *CaAPX5* involves in plant growth under drought conditions. When coffee plants are grown in invitro and in vivo, some of the plants grow poorly and some die due to poor growth. To overcome this type of problem VIUSIDAgro^{TM} biostimulants can be used (Laisyn et al. 2021). Molecular markers which are linked to physiological traits are useful for physiological studies (Achar et al. 2015). The *arabica* and *canephora* genotypes were characterized with 40 SSR and 29 ISSR primers to study the dissimilarity ranges by using the Jaccard Similarity Index (JSI) (Motta et al. 2014). 0.3 & 0.346 PIC values with SSR and SRAP markers were observed in *arabica* plants (Mishra et al. 2012; Moncada and McCouch 2004). Genetic diversity in *robusta* hybrids and their parental genotypes was checked with SSR and RAPD with the rages of 51.5% & 51.6% polymorphism (Gimase et al. 2014). Similarly, 21 RAPD Primers found 42% of polymorphism in 24 coffees inter specific accessions (Kathurima et al. 2012).

Coffee plants have a complete genome sequence of 710 Mb in *C. canephora*, 1.3 Gb in *C. arabica*, and the chloroplast genome of *canephora* is 155189 bp with 79 protein genes. The SNP markers have also played a key role in studying the genetic diversity of coffee plants. A total of 33239 SNPs in *arabica* and 87271 SNPs in *canephora* were found as well as 386560 SNPs in seven *C. canephora* genotypes were found by next-generation sequence (Dereeper et al. 2014). More about SNPs in *arabica* plants was briefly explained by Simone et al. (2020). The 11187 SNP marker in *arabica* plants and 6696 SNPs in wild accession of *arabica* plants showed 0.35 and 0.38 PIC values (Sant Ana et al. 2018; Sousa et al. 2017). Spinoso-Castillo et al. 2020 was studied the genetic diversity of a total of 87 genotypes using DArt seq and found 1739 SNPs with a PIC value of 0.10.

Coffee crops are affecting by diseases and causing severe damage to the farmers hence, researchers developed markers to screen the disease-resistant plants. Gichuru et al. (2008) developed a sat 207 and sat 235 markers from 57 SSR and 31 AFLP primers to detect the coffee berry disease (CBD) resistance plants in hypocotyls and young seedlings. Hibrido de Timor (HdT), Rume Sudan, and K7 coffee varieties have a specific gene for tolerance to CBD was characterized by using the 22 RAPD markers (Charles et al. 1997). SSR markers sat 235 and sat 207 were used to find the CBD and coffee rust disease (CRD) these markers are closely associated with the *CK-1* gene (Alkimim et al. 2017). The T, R & K genes from HdT, Rume Sudan, and K7 genotypes were assembled in Ruiru11 (R11) and Batin varieties by using a molecular approach and Dr Tseq to develop the CBD resistant plants (Gimase et al. 2021).

Coffee leaf rust (CLR) diseases also causing severe damage to the crop hence, molecular markers have been developed to find the resistant plants. Genetic diversity was checked in F2 generation plants by using 33 AFLP and 13 SSR markers which showed high polymorphism later same plants were allowed to bioassay with *Hemileia vastatrix* to check the rust resistance (Juan et al. 2009). The offsprings of the Hirbrido de Timor (HdT) cultivar also showed coffee rust disease-resistant by the presence of resistance gene (Pestana et al. 2015; Sousa et al. 2017). The SH3 gene was closely linked to SSR and SCAR markers have been found during the characterization studies of *arabica* plants for rust resistance (Lashermes et al. 2010; Mahe et al. 2008; Valencia et al. 2017). *Meloidogyne exigua* nematode resistance plants were also found by screen the SSR markers in the F5 progenies of HdT 440-10 and Catuai Amarelo IAC 86 genotypes (Pereira et al. 2016). Some molecular markers fully or partially associated with disease and other trait resistant gens were shown in Table 5. The genetic linkage maps for yield, height and bean size were constructed by using a different molecular marker in coffee plants (Moncada et al. 2016). The molecular markers used not only for biotic and abiotic problems, also be used to find the high caffeine content plants by using 11 SNP markers which are closely associated with the caffeine biosynthesis pathways (Tran et al. 2018). Anagbogu et al. (2021) was discussed about type of lipids, their main roles in cell metabolism, and understanding of lipids network in coffee plants. Tadesse et al. (2021) was assayed genetic diversity in 40 coffee varieties by using 14 SSR markers and 7.5 polymorphic alleles with 80% polymorphic information content (PIC) was observed among the varieties and the hybrid varieties were developed by crossing among high genetic diversity varieties. Total 192 SNP markers were used to study the genetic diversity in 400 coffee canephora varieties

Table 5 Partially- or fully-linked molecular markers for some traits

Resistant trait	Marker name	Marker series	Genotype name	Reference
CBD	RAPD	M62027, M20830,N18250	*Coffea arabica*	Charles et al. 1997
CBD	SSR	Sat 207,Sat 235	*C. arabica*	Gichuru et al. 2008
	AFLP	ACT-CTT-h, AAC-CTG-a, ACC-CAA-e, ACT-CTT-f, ACT-CAA-c, AGC-CTG-c, AGC-CTG-d, AGC-CAT-a		
CLR	SCAR	BA-48-210-f, SP-M8-SH3	*C. arabica*	Mahe et al. 2008
	SSR	Sat 244		
	AFLP	M5, M8, M16,M18		
CLR	AFLP	AA-11, 12, -13, -14, -22, CC-14, -21, -22, AC-14	*C. arabica* and *Coffea canephora*	Juan et al. 2009
	SSR	Sat 225, Sat 229, Sat 259		
CLR	AFLP	E.CTC/M.TTT405, E.CCT/M.TTC230, E.CGT/M.TGT300	*C. arabica*	Giovani et al. 2010
CLR	SSR	Sat 160, Sat 281 (near to the SH3 gene)	*C. arabica*	Lashermes et al. 2010
Rust disease	SSR	Sat 244	*C. arabica*	Prakash et al. 2011
	AFLP	BA-124-12K-f, Sp-M8-SH3 (closely linked to the SH3 gene)		
Coffee rust	SCAR	ETCA-EATG560, ETGT-EGGG350, ETCA-EAGA530, ETGC-EACA320, ETGT-EACA480, EGTA-ETGA605	*C. arabica*	Valdir et al. 2011
For diversity study	RAPD	OP- E, F, G, I, J, K, M, N, X, Y	*C. arabica* and *C. canephora* genotypes	Kathurima et al. 2012
	SSR	M24, Sat 235		
CLR and CBD	SSR	M24, Sat 235	Robusta	Gimase et al. 2014
Root length	RAPD	CM21130, CPCM13400, OPS1850, OPY201200, OPZ101350	C. canephora	Achar et al. 2015
Root dry weight	RAPD	OPL11400	*C. canephora*	Achar et al. 2015
Root-knot nematodes	SSR	SSRCafé 32 allele 2, SSRCafé 19 allele 2, SSRCafé 20 allele 1, SSRCafé 37 allele 2, SSRCafé 13 allele 5, SSRCafé39	Híbrido de Timor 440-10 Catuaí Amarelo IAC 86 progenies	Pereira et al. 2016
CLR and CBD	SSR	Sat 235,Sat 207	C. arabica	Alkimim et al. 2017
CLR	SCAR	BA124-12K-f (closest to the SH3 gene)	C. arabica	Valencia et al. 2017
Lipid content	SNP candidate genes	S1_24382872, S2_14041151, S2_20725291, S6_36332719,S8_25559761	C. arabica	Sant Ana et al. 2018
Identify of high caffeine content	11 SNPs		C. arabica	Trans et al. 2018
CBD	Candidate genes	T,R, and K genes	C. arabica	Gimase et al. 2021
Drought tolerance	Candidate genes	*CaMYB1,CaERF017, CaEDR2, CaNCED, CaAPX1, CaAPX5, CaGolS3, CaDHN1,CaPYL8a*	IcatuVermelho IAC 3851-2 × Catimor UFV 1602-215 progenies	Santos et al. 2021

collected from different places and assayed by using Kompetitive allele-specific PCR (KASP) (Akpertey et al. 2021). The above molecular level studies were more useful to the breeders and researchers to improve the coffee crop. The transgenic approaches are also playing crucial role in the coffee crop improvement and so far developed transgenic coffee plants were discussed by Banavath et al. (2019).

CRISPR / cas9 is an amazing, fast, and accurate usable technology in crop improvement. This technology has already made the genetic changes required in many crops to be resistant to viruses, fungi, bacteria, abiotic stress tolerance, nutritionally rich and ornamentally beautiful plants. In *C. canephora*, the *CcPDS* gene edition was done using *Agrobacterium* mediated genetic transformation for the observation of color phenotype. The *P*^{COFEBIT} binary vector with *U6* promoter was used and 30.4% mutation frequency was observed (Breitler et al. 2018)

Challenges

Global warming is affecting every natural resource on this planet. Coffee cultivation is facing more problems by increasing the global warming. If some steps are taken to grow more trees in hilly areas the rain will likely fall on time, as a result, the climate temperature effect can decrease and ground water levels will be increased. Due to the presence of large trees on the hilly areas, cultivation of coffee plants will become easy. Hence, coffee plants can grow healthily and give good yields.

As the rain falls more than necessary, disease vector populations will become more so that, coffee plants get affect for more diseases finally, farmers and coffee industries fall in trouble (Bett et al. 2017). Most of the farmers are not able to spray pesticides for the diseases (Bebber 2015). There is robust evidence that pests and diseases have already responded to climate change. According to Sami and Peterson estimations 50% of insects can be get change by 2100 under current GHG (Green House Gas) emissions trajectories. For example, Climate change influences on the global potential distribution of bluetongue virus (BTV), which is spread by biting *Culicodes* midges (Samy and Peterson, 2016; Warren et al. 2018). By facing so many crop issues coffee growers are gradually declining due to inadequate marketing and inadequate rates (https://www.sigfox.com/en/news/how-rainfall-affects-crop-health). Due to having high temperature and spraying more pesticides lots of useful insects is going die which involve in pollination. Loss of pollinators also creates more damage to agriculture (Goulson et al. 2015; Le conte and Navajas 2008).

This type of problems can be overcome to some extent by supplying genetically modified plants (GM) which are biotech plants to get rid of such problems. Current crop development technology must be used to provide food for the growing population that can withstand this climate change, disease, and other consequences (Ahmad and Mukhtar 2017). Thus the percentage of farmers who cultivate coffee can be increase. Similarly, it is better to use poly vinyl houses for drying coffee beans. To have a healthy future we need to look for sustainable coffee options that will thrive in all kinds of weather conditions. Doing so does not harm society and we will get the full benefits of the drink by making coffee from sustainable and quality coffee beans so that, justice is will be done to everyone who involved in the coffee supply chain. This is the right step in the direction of providing a better life for future generations. Therefore, coffee growers need to adopt methods for cultivating cytoplasmic genes of different diploid species as cultivars to withstand disease attacks and sustain production in a changing environment (Santa Ram 2018). As per the above discussion it is advisable to use genetically modified plants and fertilizers containing nanoparticles to give better yield in present world scenario.

Conclusion

Coffee crop giving more economic support to the countries hence it is needed to protect the crop from various aspects. we have discussed how to grow coffee plants from seed stage to plants and required salts in the soil, and favorable conditions to the plants for healthy growth. While harvesting the beans more precautions have to take otherwise farmers will be getting more income loss. Hence, the precautions have been discussed from the harvesting step to packaging. We hope these techniques are useful for all farmers and mini industries. Due to more fungal and bacterial diseases crop loss is increasing every year hence here we explained the methods to prevent common fungal and bacterial diseases of coffee plants, along with their causative agents. Nanotechnology is the new technology in the agriculture field. We explained the uses and benefits of different nanoparticle- fertilizers and nanopesticides to increase coffee production by overcoming the biotic and abiotic issues. Although we discussed polymorphisms with the different molecular markers in coffee plants, various markers need to develop for selection of disease-restance and other traits.

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